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THE EPISTEMOLOGICAL PROBLEMS OF BIOLOGICAL SYSTEMS MODELLING

-USSR-

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Modelling as a theoretical and experimental research tool has been known to biologists for a long time. It has only been recently, however, that this technique has acquired such qualitatively new features as would make it an extremely effective and necessary means of scientific analysis. Modelling affords an extremely vivid conception of the methodological aspect of modern biological research trends. In any case, it is directly connected to some of the distinguishing characteristics of the latter, namely, the trend toward increased integration of scientific disciplines, the introduction into biology of methods employed in the allied sciences, and the enormously heightened role of the precise experiment in its relation to modern logical and mathematical descriptive techniques and to the explanation of biological facts. Modelling is one of the more readily apparent results and indications of the integrative process now going on in the sciences. It is moreover, one of the prerequisites for further development in this direction in its creation of reliable "channels of communication" among the allied sciences which make possible the growth of mutual influence in the latter.

The Modelling Concept: its Varieties and Functions. Model and Theory

In its most general and widely-used sense, which will of course require further elaboration and concrete definition, modelling denotes the material or mental simulation of an actually existing (natural) through the special construction of analogues (models) which duplicate the

organizational and functional principles of this system. There are two basic types of models--the material (concrete, and in this sense physical) variety, and the ideal (logico-mathematical, etc.) type.

The above definition of the concept of modelling appears to be perfectly clear at first glance. Furthermore, the only possible sources of dissatisfaction seem to be the reasons for doubting the clarity of the definition. This, however, is far from true. Our paramount concern here is the concept of the model per se, or, more precisely, the criteria to be applied in defining this concept. It is self-evident that these criteria are far from identical to the largely intuitively comprehensible basis for distinguishing model varieties which assures a practically reliable means of orientation to any researcher having sufficient experience in the manipulation of modelling concepts.

Paradoxical as this may seem, the vagueness, insufficient logical rigor, and finally, the simple ambivalence of the concept of a model turns out to arise from its originally supposed triviality. We have in mind here the fact that at the beginning (and in many cases up to the present time), that the generalized concept of the model had constantly included merely one of the possible model varieties, namely the physical model. The latter corresponds to the word "model" in its literal sense, that is, in its designation of the model as an adequate and visually perceptible copy of a natural system or an original. The differences of such a model from the original are quite obvious. At any rate, they (let us be more cautious) are obvious to a degree sufficient to exclude the ambiguity of results in the process of research practice utilizing such models. If, however, we attempt to transfer mechanically that basis which is implicitly contained in the concept of a physical model on to, let us say, a logical model, then the latter will (without additional explanation) be rendered impotent to play the role of a model, in so far as in a definite sense it is inadequate to the object which it is supposed to simulate during the research process.

These considerations receive an extremely well-grounded treatment, comprising a portion of an article on modelling problems by A.A. Zinov'yev and I.I. Revzin entitled "The Logical Model as a Scientific Research Tool" (Voprosy Filosofii, No 1, 1960). The article contains yet another constantly reiterated thought which we feel deserves attention at this point. What we have in mind is the following. It is a known fact that the analogue is the basis of the structure of all model varieties. As is noted by

A.A. Zinov'yev and I.I. Revzin, the construction of analogues is far from being identical to the devising of models. The authors write: "It is only in cases where on the basis of the establishment of analogies for various objects one of them is subjected to investigation as an imitation of another, and where the resultant knowledge obtained from one serves as a necessary point of departure for conclusions as to the other, that we are dealing with models" (page 83).

This limitation is of extreme significance. Taking it into account, it is possible to render a concrete definition of the concept of modelling which does not represent it as the mere construction of isomorphic substitutes for the original. The mental or physical imitation of the latter will emerge in the role of modelling only when it serves the aims of research. This means that any model must be of a heuristic character. It follows from this, however, that the principle, fairly commonly used by scientists, for subdividing models (according to function) into two classes--heuristic models, and models for direct practical application (industrial automation devices for the artificial "replacement" of certain physical functions of the organism; electronic computers performing the work of the human brain, etc.)--is not logically justifiable from this point of view. Structures of the second class mentioned above do not belong to the category of models if their functions are opposed to functions of a heuristic nature. It should of course be borne in mind that these structures are frequently used with some success for research purposes as well. But it is only in this case that they are to be looked upon as models of objects under investigation, namely as physical models.

This question requires closer scrutiny, and we shall return to it in the course of our discussion. At this point, however, we should like to direct our attention first of all to the fundamental importance of the concept of models only as <u>heuristic</u> substitutes for the object under investigation.

When it is emphasized that this or that theoretical construction in science has but a heuristic character, the intent is usually one of distinguishing this construction from all of the others not only as to function, but also according to its fundamental essence (conditionality, limited adequacy, etc.). In the final analysis, it is a matter of bringing to the fore that which distinguishes, let us say, a logical model of a given biological phenomenon from its theoretical reflection in the form of a biological law.

In taking as our criterion for distinguishing between model and theory, the fact that the model is but a <u>means</u> whereby the theory is formulated, we establish a definite

functional characterization of models and modelling in general. This, however, is as yet patently insufficient. After all, models are not the only foundation and means of constructing theories, since, for example, other theories can play this role as well. It is, furthermore, completely unnecessary to reduce this theory to the level of a model representation. The latter procedure can only lead to an unjustified complication of the investigative process and the introduction of an entire series of auxilliary formalisms playing a strictly supplementary and secondary role.

Any model constitutes a certain simplified representation of that class of phenomena which happens to be playing the role of the investigative object. In the opinion of A. Rosenblueth and N. Wiener, this fact constitutes the distinguishing characteristic of the method of modelling (see A. Rosenblueth and N. Wiener, "The Role of Models in Science", in <u>Philosophy of Science</u>, Vol. 12, No 4, 1945, pages 317-320). It is not only the model, however, but rather any scientific law which within certain limits simplifies the object of knowledge. These limits change when, in the process of scientific investigation, there is a transition to an interrelated system of laws or a theory covering the object phenomena. Nevertheless, a certain degree of simplification of the actual relationships does, of course, remain even in this case. The question arises of whether one should then look upon simplification as a peculiarity of the modelling method. An affirmative answer to this question may be given with one significant reservation, which will take us back to what has already been said about models at the beginning of this article. The idea in mind here is the fundamental difference which exists between the character of simplification admissable in the modelling process, and the simplification which unavoidably arises in the course of the theoretical research process in the manipulation of scientific concepts and laws. This difference is manifested in the levels of simplification. In particular, for the case of theory, this level is clearly determined by its adequacy in representing the reflected object. As regards the model, the adequacy criterion (in the usual sense) is not a mandatory test of validity. The foregoing does not, of course, imply that the simplification of the object under study resulting from the application of the modelling method has no limits of its own and fully excludes the adequacy principle. But the specific nature of modelling concepts consists precisely in the peculiar status of the adequacy principle within the given context. This peculiarity does not merely reside in the fact that, for example, logical models exclude such considerations as representational accuracy and clarity,

but rather mainly in that for the case of modelling, the matter is one of conditional adequacy whose presence is "initially specified" in the form of a logically founded admission.

Simplifications peculiar to the modelling method are consequently obtained in the form of heuristically useful analogues bearing a nearly conditional correspondence to the modelled object. This conditionality depends both on the character of the simplifying admissions and on those auxilliary hypotheses which guide the modelling process. It can thus be understood, that models (due to their inadequacy or mere "conditional adequacy), in contradistinction to theories, do not afford an explanation of the modelled object directly and in the form of homologous dicta. They do, however, create a basis and afford means for the explanation of theoretical principles apposed to a given object.

In addition to this, one cannot but notice that the heuristic, conditional character of models in itself does not exclude their explanatory functions. The role of models is in no case reducible to the mere description or demonstration of phenomena under investigation. They do, in fact, contain explanations which, however, differ from those afforded by the scientific theory covering a given object. This difference lies in the fact that the explanations of the former variety (in relation to the modelled object, but not, of course, in relation to the model itself as an explanatory object) play the role of conditional explanations, or quasi-explanations which nevertheless have an enormous heuristic and cognitive value for the subsequent formulation of homologous, adequate dicta within the framework of the scientific theory covering the object under investigation. What are the reasons for the fact that models, biological models in particular, are merely conditionally adequate to their original and afford only a quasi-explanation thereof? We shall attempt to explain this in our discussion of the problem of limits in modelling and its connection with the theoretical interpretation of the investigative object. What we have in mind are, of course, ideal (logical, et al.) models. For this reason, let us emphasize, a characterization of model explanations as quasi-explanations cannot be looked upon as general for all model classes. It does not apply, in particular, to explanations obtained in the study of the functional principles of those physical models which are simply quantitatively altered "copies" of modelled objects. In other words, for example, it is possible to construct in technology physical models whose adequacy to the

original will not be of a conditional nature provided that the differences between the two are related to their non-qualitative aspect (the incorporation in the model of essential properties of the original), and rather to their purely quantitative side (lack of geometric correspondence, differing scale, etc.). Quite obviously, this possibility is almost totally lacking in the case of biological models, since in the more typical instances, the differences are of a qualitative order. This is indeed understandable; after all, in the contrary case, the modelling of biological objects would lose all meaning, since it would not introduce the necessary simplification into the situations studied.

Modelling and Artificial Duplication

In a general characterization of the concept of modelling, it is of paramount importance not only to distinguish between model and theory, but also to examine modelling (in particular, physical modelling) in its relation to the problem of artificial duplication. This is no wise an idle question in modern biology; it is rather of the highest practical importance and timeliness.

It has already been noted above that physical modelling has to do with a specific class of isomorphic substitutes, which, taken in another (for example, purely practical and utilitarian) context, would be excluded from the category of models. It is important to note here that the physical model is tied in in its specific functioning precisely with the context in which it is viewed, and not with the quality of its "substratal" properties, which means that the model can be both artificial and natural. This implies that the role of a model for a given biological system can be played by another natural and not especially constructed system (a lower organism with relation to a higher one, etc.).

A natural system not looked upon during the course of the investigation as an isomorphic substitute for another system will, of course, not be called a model. How does one then explain the fact that artificial physical substitutes are included by many scientists in the class of models without referring as to whether they serve research purposes or not? The answer to this question, as it turns out, is closely connected not only with the understanding of the modelling concept, but also with the interpretation of artificial duplication. The fact of the matter is, that many scientists do not regard it as possible to include in the concept of artificial duplication, for example, a large class of specialized structures (in particular cybernetic devices) which imitate certain aspects of the functional

activities of live organisms. In following this procedure, it is asserted that artifical duplication is essentially a mere biochemical synthesis of live systems, directly and exclusively tied in with the duplication of a specific substrate in the living object. It is well known, however, that if one looks upon the functional aspect of substratally distinct systems, one can easily detect a partial correspondence, which, though differing in degrees of expression, is a true correspondence nevertheless: numerous functions are duplicated in nature on differing substratal bases. In this sense, it is possible to assert that nature abhors fetishes. They are created by man himself, and it is he who renders them absurd and constantly destroys them as he proceeds along the path of historical progress. Thus, the amusing question posed by a man who had just heard an explanation of the workings of a tractor: "But where have you hidden the horse?" -- belongs precisely to this category of "substratal fetishism". One nevertheless frequently hears something similar during discussions of problems connected with the cybernetic duplication of certain functions of the live organism.

It is imperative, therefore, to take as the basis the fact that artificial duplication is not connected exclusively with the biochemical synthesis of living objects which would duplicate both the specific substrate peculiar to the given organism and the organism's functions, but rather that it is possible to reproduce partially certain functions on a substrate base not specific to the live organism. It is precisely to this category of artificial duplication ("functional duplication") that the cybernetic structures belong in particular, in so far as they are regarded apart from their relationship to research aims.

There exists a deep inter-relationship between modelling and artificial duplication which is of great interest for the study of biological research dialectics. It is known that, for example, technological progress constitutes to a certain extent, a number of successes achieved by man in duplicating the functions of the live organism. Cybernetics arose as a science one of whose main purposes was the study of the means and techniques of technological duplication of the functions of the live organism. In other words, cybernetics was from the very first confronted with the task of "teaching" automatic devices to operate on the basis of these most economical and effective principles of all those which exist in nature. Modelling thus became a point of departure and a means of bringing this goal to fruition.

The artificial duplication in technology of the more complex functional principles operative in living systems is a fundamentally new trend in technological development. Science has essentially just begun to scratch the surface of this promising field. Modern science is just beginning the study of the modelling and duplication techniques to be used, for example, in simulating the self-regulation and adjustment to optimum work conditions so characteristic of even the simplest living beings. The future of this field holds limitless possibilities and portends truly fantastic results. This applies, in particular, to the artificial (technological) duplication on an inorganic substratal basis of the process involved in the direct transformation of chemical into mechanical energy which proceeds with such a high efficiency in the working muscles of animals. Preliminary modelling can also be used to realize a task as grandiose as the one of artificially duplicating the photosynthetic process under experimental and industrial conditions; this would provide mankind with a means of making optimum use of solar energy, placing at his disposal practically unlimited resources of organic substances derived directly from inorganic material.

Perfectly obvious likewise, is the connection between modelling and the artificial duplication of the simplest living systems. It goes without saying that the successful solution of this problem is impossible without the preliminary creation of a whole number of models which would make possible the experimental study of specific aspects of the life-functions of organisms. There is no need to speak of the importance of the results of this complex and difficult work, not only in the practical and theoretical plane, but in the more inclusive one of philosophy.

The modelling of biological processes creates a fundamentally new approach to the solution of questions connected with the artificial duplication not only of the functional aspect of live systems, but the principles of their structural organization as well. It is known, for example, that modern computers which within definite but constantly widening limits are able to imitate the functional mechanism of the brain, constitute enormous component assemblies whose individual units are nevertheless incomparably less efficient than neural cells. The utilization of semiconductors to a certain extent facilitates the solution to the problem of creating more perfect and "versatile" cybernetic devices without the usual concomitant dimensional increases. This, however, does not yet constitute the solution to the problem as a whole. It is possible only on the basis of great future discoveries in the field of the live modelling of

living system structures, which will lead to the creation of devices approximating in compactness those "invented" millions of years ago by living nature.

The interconnection of modelling and artificial duplication is manifested not only in the fact that the latter depends upon modelling as its theoretical and experimental foundation and the determining factor which makes it a possibility. This interconnection is likewise apparent in that the results of artificial modelling made possible with the aid of modelling can themselves play the role of models or of bases for a whole number of new models. Convincing evidence in favor of this supposition may be found, for example, in cybernetics, which is in turn exerting an enormous amount of influence on biology.

It is necessary at this point to note yet another extremely important consideration bearing a direct relationship to the epistemological problems of modelling under discussion. The issue at hand is that artificial duplication of biological processes on the basis of modelling not only transforms the notorious "thing in itself" into a "thing for us", thereby practically refuting the agnosticism still being preached by certain bourgeois philosophers and some of the modern biologists trotting along at their heels as regards the possibility of knowing the "secrets" of living nature. The duplication of biological processes under industrial conditions constitutes simultaneously (on the epistemological level) a reliable criterion for judging the certitude of scientific knowledge as to the laws governing the functions of live organisms which are theoretically and physically incorporated into the biological model.

Some Peculiarities of Biological Objects as Systems

Biological modelling is immediately confronted with the problem of representing living objects in the form of such logically justified propositions as would permit one to look upon the peculiarities exhibited by organisms as specific "individual cases" of more inclusive classes of phenomena. Generalizing concepts of this variety are contained, for example, in the theory of systems which has received extensive development within recent years. Models based on the representation and logical-mathematical investigation of organisms as systems of a definite type have become extremely widespread in modern science and have proven their heuristic value for biological investigation in general.

This, if one might call it such, systemic modelling quite naturally can not be looked upon as a means to be

counterposed in absolute form to all other biological modelling techniques. It is, moreover, difficult even to speak of any special method of modelling. The granting of a special status to this particular method, however, may be found useful to a certain degree, in so far as in this case there is a more specific emphasis on the "point of view" from which modelling is considered.

In contradistinction to chaotic aggregates, organized systems (which obviously include organisms) are characterized by a regularity of interaction among their constituent components; this regularity is, of course, perceptible in varying degrees. These varying degrees of process regularity depend on the organizational level of the system and can be denoted by the concept of information quantity. As is known, the classical concept of entropy is also connected with this notion. "Just as the quantity of information contained in a system is a measure of its organization", writes N. Wiener, "so the entropy of a system is a measure of its disorganization; one is equivalent to the other, qualified by a minus sign" (Norbert Wiener, Cybernetics or Regulation and Communications in the Living Organism and the Machine, Moscow, 1958, page 23).

Living organisms, quite apart from their position on the "hierarchical step-ladder", belong to the so-called "open" category of organized systems (or simply systems). What is the distinguishing characteristic of such systems? Systems designated as open are contrasted with other systems, looked upon in physics and chemistry as closed and isolated. The latter are grouped under the general designation of closed systems and are characterized by their lack of participation in exchanges with the external medium either of matter only (closed systems), or both matter and energy (isolated systems). Each such system, according to the second law of thermodynamics in the final analysis reaches a time-independent state of equilibrium with maximum entropy and minimal free energy. In the equilibrium state, such systems are incapable of doing work.

The ability to do work is connected with the emergence of the system from the equilibrium state; in order, furthermore, for the work to be done over an extended period, the system must be in a state of mobile (dynamic) equilibrium, receiving a constant flow of free energy. A necessary condition for the maintenance of the unstable equilibrium state is the strict balance in time of the rate of irreversible chemical processes and of matter diffusion. A definite stationary state for the system is necessarily reached provided that the above-mentioned rates are maintained constant. Such processes are characteristic of open

systems. They can be observed, for example, in chemical technology (the continuous fermentation process in the manufacture of acetic acid, etc.). These processes are likewise peculiar to living organisms, constituting a typical example of open systems.

An open system is, consequently, characterized by its constant exchange of matter and energy with the surrounding medium, as well as by its ability under definite conditions to enter into a time-independent state of mobile equilibrium, wherein the properties of this system remain constant despite the continuance of the processes of interaction with the external environment. The entropy of an open system in the state of mobile equilibrium ramains constant but differs from the maximum. This state of affairs is attained through the compensation of potential increases in the entropy by the extraction of "negative entropy" from the surrounding medium.

It is hence apparent, that the organism as an open system retains its characteristic morpho-physiological unity (and generally functions as a living organism) just so long as it remains in the state of mobile equilibrium, that is, as long as it maintains a time-balanced mutually-compensated process of constant change in its constituent components, a process of assimilation and dissimilation from and into the surrounding medium. With certain simplifications, this state of mobile equilibrium can be simulated in models based on simpler objects. For example, an ordinary stream of water flowing from a faucet can serve as a model for the study of certain isomorphic properties of this state. And indeed, the form of the stream remains constant as it were, as long as the flow from the faucet is uniform. It is perfectly obvious, however, that the form of the stream which is in a state of equilibrium is not determined by the constancy of its constituent components--the water molecules, but on the contrary, by their uniform entry into and exit from the given system.

It is, of course, necessary to bear in mind that living organisms differ fundamentally from all others (for example, from the usual open chemical systems) by virtue of their special type of organization and constituent component interaction. The foregoing can be set down as a generalized, but insufficiently definite notion of an organically unified system.

An organically unified system is one comprised not only of temporally and spatially coordinated, but also functionally inter-related components, each of which is characterized by its own specificity and is, at the same time, strictly subordinated to the whole. A special type of

component interaction in an organically unified system assures the self-maintenance (autoregulation) of its internal medium; moreover, this homeostatic regulation, carried on under the conditions of constant interaction with the external medium, reaches its highest limit of perfection in connection with the emergence and development of the nervous system.

The peculiarities of organisms as systems cannot be reduced only to those which can be isolated with reference only to individual specimens. As is known, the systematism of the latter emerges simultaneously in the role of a complex component (or subsystem) of a new type of organically unified system peculiar to the species and populations in which it is found. Although the species and the populations which comprise it is a divisible whole, functional interactions among its components are likewise subject to the realization of the same process of self-preservation and propagation which operates within individual organisms. From the standpoint of the thermodynamics of stationary irreversible processes, a biological species, just as the biosphere as a whole, can be looked upon as an open system.

Information Theory and Biological Systems Modelling

Models of biological objects constructed on the basis of the general theory of systems afford a precise quantitative technique for the study of specific laws characteristic of the functioning of organically unified living systems. Extremely fruitful steps in this direction have been made, for example, by L. Bertalanffy, who attempted to render a symbolic representation of changes in a system somewhat removed from the state of equilibrium but, as it were, "striving" to reach this state at some future time (see L. Bertalanffy, Der Organismus als Physikalisches System Betrachtet, in Die Naturwissenschaften, Heft 33, 1940, pages 521-531). The formulas which describe the behaviour of a system under non-actual conditions serve to distill out that peculiarity of the behaviour of live organically unified systems which is expressed in the concept of organic teleology [used here in the limited sense] and in this case denotes a certain dependence of the actual developmental stages in such systems (for example, in embryogenesis) on the gradual result of this development, or, in other words, a subordination of the development to the "plan of the whole". Of course, along the path of the mathematical description of this functional peculiarity of organically unified live systems, it is still necessary to overcome certain rather serious difficulties, one of which is the

danger of "over simplification" in describing the phenomena at hand (a certain amount of simplification is, to be sure, unavoidable within definite scientific limits). In addition to this, there is a need for a sharp renunciation of all manner of teleological, "finalistic" speculations which tend to introduce a note of mysticism into this scientifically established property of living systems.

For biological studies, however, it is necessary to have at hand a mathematical description not only of the specific functional peculiarities of organically unified systems but also of those non-specific mechanisms which make possible the attainment of the purposeful result of these functions. The description of these mechanisms assumes special interest in connection with the problem of systemic modelling. It turns out in this connection that the interaction processes between individual components of an organically unified system do not fit the concept of a mechanically interpreted single-valued causal relationship, and that during the course of this interaction there arises a certain statistical factor, a definite uncertainty, which can be explained by the intervention into the regular course of the process of various types of "malfunctions" of an objectively incidental character. When dealing with an individual organism as a specific investigative object, we are justified in exercising a certain experimental and mental isolation which permits us to regard the regularities qualitatively and quantitatively determining the reaction of this organism as a whole, as regularities within a single object, in other words--as dynamic regularities. In making the transition to a more detailed analysis, however, which divides the organism into individual interacting components, we are immediately confronted with statistical regularities, wherein the only determining factor is the combined behaviour of these components, while the action of each of them bears a readily apparent character of uncertainty. It is moreover self-evident, that this fact does not depend on the precise level of the division of an organically unified system. The division may be undertaken both on the level of biochemical interaction among individual cells and on the molecular level. It can also be performed on the population level, where the individual organism itself will play the role of a single component within a definite system.

In what form does modern science make possible the quantitative study of these peculiarities exhibited by live systems, and what are the models created by science in the course of such investigations? A particularly

great role is played in this area by the application of probability and information theories. The theoretical foundations of this branch of modern mathematics, in particular, such fundamental concepts as probability, information, and entropy are sufficiently well known to obviate the necessity of stating them in the present article (see, for example, the work of A.M. Yaglom and I.M. Yaglom, Probability and Information, Moscow, 1960).

A living organically unified system functions in constant interaction with its medium. This interaction is realized in the form of adjustment and is regulated by the natural selection of useful changes in the living system. These changes themselves tend to be uncertain and constitute a statistical combination of random events, where the final result--adjustment--can be attained only with a definite degree of probability. The latter applies with equal force to the behaviour of populations. It is precisely for this reason that information theory and all of the attempts to construct on its basis various types of models, even in such fields of biology as genetics and evolution theory, are presently attracting the attention of biologists.

An organically unified living system can be modelled in such a way as would render its substratal nature irrelevant in the specific context. The main emphasis will be placed on the quantitative and qualitative description of its functional principles, in particular on the laws of information transfer and transformation, regardless of the nature of the communications channels. The task of the biologists seeking to employ the methods of communications theory to the analysis of biological problems will consist in finding analogues to the communications system in morphophysiological descriptions of organically unified living systems. Such an analogy is established, for example, in the course of studies on the reflexive nature of higher nervous activity in animals and man. With certain definite qualifications, however, this analogy retains its applicability in the examinations of the functional principles of any living system. In such cases, the medium turns out to be both the source of information and the destination point of the "messages". All of the other functions of the communications system (information reception, processing, and transfer) are carried on directly by organisms which have survived due to the fact that they have been able to follow along and adjust to environmental changes in accordance with the quantity and quality of information obtained from this environment. The phenomenon of adaptive alteration in this context assumes the role of a homeostatic regulatory condition, while natural selection becomes a

special type of regulatory mechanism which automatically emits a reverse flow of information as to the benign character of a given alteration in the living system.

Viewing the influences exercised by the external environment as peculiar sources of information, as well as factors altering the effect of various types of abiotic and biotic "malfunctions", the biologist can on the basis of probability theory, formulate predictions regarding the possible state of a given organic unified living system at a definite moment in time which is of interest to him. This permits him to make more precise studies of complex processes at various levels than would be possible with the aid of the standard qualitative biological techniques. It is important to note that in all of these instances, the matter at issue has to do with the application of strict mathematical methods enabling one to study and compare random phenomena characterized by varying degrees of uncertainty.

From this standpoint, there is extreme value for biological research not only in physical models, but also in a whole series of model concepts arising out of cybernetics. The latter, incidentally, was responsible for drawing the attention of researchers to the principle of reverse communication and its role in the functioning of organically unified systems.

In order not to fragment our exposition, we shall not pause to consider the various forms of reverse communication exhibited by living systems (in particular, completely neglecting its highest form), noting only that this principle has a <u>universal</u> character in biology. In this connection, any attempts at emphasizing from among the open living systems a type which could be characterized in definite contradistinction to the principle of reverse communication must, in our opinion, be apposed with serious qualifications. This applies, in particular, to a type of open system singled out by L. Bertalanffy, one of the founders of the theory of systems, which is based only on the dynamic interaction of its constituent parts (the so-called "equivalent system"). In this case, reverse communication is regarded by him merely as a certain fixed mechanism having a secondary regulatory character and constituting an outgrowth of the primary dynamic interaction processes formed during the subsequent development of the organism.

Among such interactions may be grouped the various correlations arising, for example, during the course of embryonic development. Even here, however, there takes place an indirect reverse communication flow, in so far as these correlations themselves represent a form or adaptation

developed historically as a result of interaction with the environment. In addition to this, the results of various correlations in embryonic development are subjected to a "critical evaluation" in the subsequent stages of individual development under the regulation of the natural selective process. The sharp contraposition of dynamic interactions within the organically unified system at the embryonic stage of development on the one hand, and the principle of reverse communication on the other, is possible only when the organism is viewed from the autogenetic standpoint, without regard for their dialectical unity with the environment in the course of individual and historical development.

<u>The Limits of the Cognitive Possibilities of Models. Modelling and Interpretation</u>

Modelling (particularly systemic modelling) represents one of the most effective, but, of course, far from universal techniques used in the scientific study of biological phenomena. It is in general possible, moreover, to regard modelling in biology merely as an <u>auxilliary</u> research method. Such a statement is occasioned by the nature of modelling.

The advantage of modelling consists in the fact that it is possible within its limits to single out (abstract) only those problems of a system under investigation which play a significant role in the given concrete context. In other words, modelling permits the singling out of definite properties which may then be studied in their "pure form"; this considerably simplifies the problems of scientific research, in so far as it enables scientists to subdivide complex phenomena that are frequently not amenable to direct analysis.

The cognitive functions of modelling correspond in this respect to those of abstract reasoning; in contrast to the latter, however, modelling may be accompanied by the construction of "physical substitutes for abstractions" that are amenable to direct experimental study. It should be emphasized the modelling always in a certain sense overlaps experiment, quite independently of whether we are dealing with experiment in the usual sense or a so-called "Gedanken" experiment. In either of these cases, the researcher makes use of modelling to enable him to study phenomena under controlled conditions, using precise quantitative indices for their description.

The advantage of modelling--the singling out of the properties of biological phenomena under investigation in the "pure form" can, however, become a shortcoming if it is looked upon as a universal research technique. As is known,

the difficulties encountered in the solution of biological problems stem from the necessity of taking into account the sum effect of numerous events on a given system. Actual living systems function not only in connection with external abiotic conditions, but also receive information from other living systems in the multi-faceted "commerce" taking place in nature. In addition to this, they themselves contain and convey in reproduction a flow of information obtained not only in the course of individual development, but also received from antecedents, that is, information as to the historical development of the species of which a given live system (individual organism) constitutes an integral part. The modelling of this aspect, although becoming ever more extensive, is still contained within fairly narrow limits with relation to the original, or, in the words of A. Rosenblueth and N. Wiener, to the "range of the model". This is the case despite the fact that insufficient attention, for example, to the history of the modelled living system exerts a considerable influence on the biological research results. If in other fields of science, particularly in physics and chemistry, such a simplification of examined situations in general does not exclude the possibility of obtaining precise results, the analogous situation as regards biology is quite a different one: a biologist will obtain only limited results if he neglects the data relating to the history of the system he is studying.

This alone already testifies to the fact that modelling must play its role in the study of living systems as an integral link in conjunction with other theoretical methods, including the historical technique employed by biology. Without such a connection with qualitative biological research methods, as well as (in a wider sense) with the theory of the modelled object, that is, with it's scientific interpretation, models can become empty and abstract constructions far removed from serving the real needs of scientific inquiry. It is important to remind the reader of this here, since perhaps one of the reasons which can explain in some measure the extremely, to put it mildly, reserved attitude exhibited by certain scientists as regards the cognitive possibility of modelling (particularly cybernetic modelling) in biology, lies precisely in the exaggeration of these possibilities, as well as in the insufficient emphasis placed on the merely supplementary role of modelling and the necessity for using it in conjunction with quantitative biological interpretation in dealing with the object under study.

Modelling in biology always has to do with the representation of a given complex system through a simpler and

more easily studied system. This means that the information obtained as a result of studying certain properties of a simple system is tacitly assumed to be valid as regards the properties of the complex system as well. However, the compared systems (for example, in the case of physico-chemical, cybernetic, etc. biological modelling) differ from one another not only with respect to purely quantitative characteristics: each one belongs to a qualitatively distinct level of material organization. As a result of this, any explanation which makes use of a model is of a strictly conditional character (it may be termed a quasi-explanation); this type of explanation is expressed in the "transference" of knowledge about one (simpler) system on to another (more complex) system. It is perfectly evident that such a "transference" cannot take place mechanically. After all, it is connected with the transition of the investigative level on to a qualitatively distinct organizational level. And here, the issue is not merely one of structural differences. The properties which are modelled on an inorganic substratal base do not represent simple "additive components" of live systems. They are organically "included" in the total functional mechanism of living systems, and their scientific explanation consequently entails the simultaneous rendition of a theoretical description covering the specific nature of the "inclusion" of these properties in the type of integral entity represented by the live system under investigation.

In order for an "inter-level" model explanation to have a real cognitive value, it must in all cases be subjected to "correction" by means of the theory which takes into account that infamous "remainder", which for the mechanists who look upon life as a simple "sum" of physico-chemical processes, turns out to be "fundamentally imperceptible", and for the vitalists, those "mechanists turned inside out", serves to this day as a "basis" for the formulation of "supra-mechanical" (and in the final analysis, of course, purely idealistic) theories of life. This "remainder" is nothing other than the specific properties of living systems. Their consideration in the process of "correcting" model explanations in passing on to the construction of a theory to cover the investigative object implies the qualitative biological interpretation of the results of "conveying" modelling concepts on to a new and higher level. Modelling, connected as it is with the extensive penetration into biology of the ideas and methods of physics, chemistry, and mathematics, is thereby not only not counterposed to specifically biological research techniques, but is also looked upon as standing in something of

a subordinate relation to these techniques. The problem consists not in making an alternate choice between the two methods and then universalizing that choice, but rather in studying concrete mechanisms which make possible the organic union of physico-chemical, mathematical and other means of live systems modelling with qualitatively biological techniques for their study and theoretical interpretation.

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Biological systems modelling brings to the fore an entire series of complex methodological problems. Attempts to answer some of these have given rise to new questions of no less importance and interest. In particular, the examination of the epistemological problems involved in systemic biological modelling necessarily leads to the posing of the question as to the precise classification of unified organic system types, the "hierarchical" unity levels in the sphere or organic life, and the possibilities for the mathematical description of the dependence of systemic entropy on the order of unity of a given system.

Of exceptionally great importance is the study of concrete logical problems connected with the utilization of dialectical methods of reasoning in the analysis of organically unified systems, such as were, for example, employed in Marx' Das Kapital (the co-ordination and subordination of the elements in a systemic pole, the methods of studying the systemic object in its "pure form", the progression from the abstract to the concrete, and the application of specific forms of analysis, synthesis, induction, and deduction in the investigation of complex systemic interconnection). There is also a need for the thorough study of problems involved in the structural formalization of the modelled system, the possibilities and concrete techniques of applying symbolic logic to the study of organically unified systems as they function with a certain degree of uncertainty, etc.

Such a multitude of unsolved or insufficiently elaborated methodological problems of systemic modelling (with reference to biology) is not unexpected. It merely testifies to the fact that in the field of systemic modelling methodology in general, there are at the present time more problems than solutions; the available solutions, moreover, contain a higher degree of conditionality and uncertainty than categorical certitude. This conclusion is perhaps not much of a consolation; at any rate, however, it takes into account the necessity for intensifying efforts in the study of these promising problems from the standpoint of dialectico-materialistic epistemology.

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